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Original research article

The influence of differing protected area status and environmental factors on the macroinvertebrate fauna of temperate austral wetlands

Toni Furlonge [a,b,*], Fiona Dyer [a], Jenny Davis [a]

[a] *Institute for Applied Ecology, University of Canberra, ACT, Australia*

[b] *Natural Resource Management North, Level 2, 63 Cameron St, Launceston, Tasmania, Australia*

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ABSTRACT

One means of conserving wetlands is to designate the area around them as 'protected'. Although many different types of protected areas exist, ranging from international (Ramsar-listed) to local importance, there is little information on how the type of protection influences biodiversity conservation. Studies of the effectiveness of protected area systems are a priority, if we are to understand their importance and design systems effectively. Many Tasmanian wetlands are regarded as having high to very high conservation values with more than 60% located within protected areas. This study tested macroinvertebrate richness and assemblage responses to a range of environmental attributes and differing types of protected area status at 66 protected Tasmanian (Australian) wetlands. Two hundred and eighteen taxa were identified with an average of 33 species (or morphospecies) and 18 families recorded per wetland. The wetland assemblages were idiosyncratic, four families contributed 21% of the total recorded and only two families contributed greater than 10%. Wetlands were not significantly nested on the basis of the composition of their macroinvertebrate assemblages. No single environmental attribute had a strong relationship with macroinvertebrate richness or assemblage composition and neither species richness nor assemblage composition varied significantly between different types of protected areas. Although the majority of protected area types were designed to support terrestrial conservation objectives rather than wetland values, our results suggest that the latter were also afforded protection. The state of the proximal zone (the terrestrial zone within 50m of the wetland edge) and the type of aquatic habitat present (macrophyte or sediment-dominated substrates) were the most important determinants of macroinvertebrate richness and assemblage composition across all types of protected wetlands. These results suggest that for temperate austral wetlands located within protected areas, the macroinvertebrate fauna will be best conserved by minimal disturbance of proximal lands.

1. Introduction

Wetlands are globally important ecosystems, occupying 6% of the Earth's surface and supporting approximately 20% of all living organisms (Zhao and Song, 2004). Yet in the last century almost half of the world's wetlands have disappeared as

* Corresponding author at: Institute for Applied Ecology, University of Canberra, ACT, Australia. Tel.: +61 0400973318; fax: +61 0363342822.
E-mail address: tfurlonge@nrmnorth.org.au (T. Furlonge).

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a result of urban and agricultural development (MEA 2005). Many types of wetlands exist. They may be natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or saline (Ramsar Convention 1987). Wetlands provide vital habitats for a range of biota as well as ecosystem services for human communities. Wetland basins form on an array of landforms, with different water regimes, and their hydrology influences physical and chemical processes within the water column. Wetlands often have a well-defined zonation with terrestrial and semi-aquatic fringing vegetation at the landward edge of the wetland, emergent and submerged macrophytes in shallow habitats and floating plants and open water regions in deeper areas (Boulton et al., 2014). Wetland ecosystems span a gradient between terrestrial uplands and truly aquatic habitats but the ecological patterns and processes in wetlands differ from those of both terrestrial environments and deeper waters (Mitsch and Gosselink 2007).

Direct drivers of wetland loss (estimated to be 50% globally since 1900) and degradation, worldwide, include changes in land use and land cover, water extraction and changes in water regimes, infrastructure development, pollution, invasive species and climate change (MEA 2005). The fundamental drivers of these impacts are global population growth and increasing economic development. For wetlands in the southern Australian island state, Tasmania, where this study was located, Kirkpatrick and Tyler (1988) found that many wetlands, particularly in the central highlands region, had been 'drowned' by artificial impoundments created for the generation of hydroelectricity in the first half of the 19th century. Wetlands elsewhere in the state had been drained for agricultural purposes and estuarine wetlands had been lost through urban landfill. Many wetlands were grazed by domestic stock and affected by a variety of recreational pursuits including fishing, duck shooting, boating and off road vehicle use. Urbanisation, mining, agriculture and forestry have increased surface run-off from exposed soils, elevating the sediment and nutrient loads entering Tasmanian waterways (Edgar et al., 2000). Water quality and aquatic habitats of both standing and flowing waters have been negatively affected, especially in lower watershed areas (Edgar et al., 2000).

The Australian federal and state governments support biodiversity conservation through various types of land protection, which, either directly or indirectly, includes the protection of wetlands (Table 1). Tasmania has approximately 2.5 million hectares of reserved (protected) land. The Tasmanian Wilderness World Heritage Area (WHA) covers about 20% of the island state and is one of the largest conservation reserves in Australia (PWS 2014). The WHA includes many wetlands. Important wetlands in Australia are listed in the Directory of Important Wetlands Australia (DIWA 2014) which is a useful database for natural resource planners and wetland managers. Australia has 65 wetlands listed as Ramsar sites, 10 of which are in Tasmania and are managed for conservation. Other forms of designated protected areas in Tasmania that contain wetlands include national parks, forestry reserves and several forms of public and private land reserves (Table 1). Sixty percent of Tasmanian wetlands are identified as having high to very high conservation value and are located in protected area reserves, with 26% in other public land and 14% in private land (DPIPWE, 2010).

Species level information is required to maximise conservation planning, however, at a global level, information on species is often lacking (Westgate et al., 2014). Environmental attributes influencing patterns of species richness and distribution differ among taxa (Kirkman et al., 2012). Congruence among taxa is often related to environmental gradients with most major terrestrial and freshwater groups richer in tropical regions than in temperate, at low elevations than at high and in forests than in deserts (Gaston, 2000). In addition to environmental factors, a range of taxa should be used for assessing conservation practises as a subset of taxa may not accurately represent biodiversity (Westgate et al., 2014). Recent studies have sought to determine congruence among wetland macroinvertebrate taxa (Ruhí and Batzer, 2014) and to identify core wetland taxa globally (Batzer and Ruhl, 2013).

Macroinvertebrates are a diverse group of taxa and they occur in a wide range of wetland types, however, knowledge of the factors that influence the structure and function of wetland macroinvertebrate assemblages is inconsistent (Batzer, 2013). The location, depth, volume and water quality of the wetland, drive the physical processes that in turn define the habitats that support aquatic biota (Boulton et al., 2014). Various factors, including hydroperiod, wetland vegetation, water quality, disturbance and biotic interactions such as predation have all been found to influence the composition of wetland macroinvertebrate assemblages (Pinder et al. 2004, Stenert et al. 2008, Davis et al. 2010, Maltchik et al. 2010, Batzer, 2013, Sim et al., 2013, Chessman and Hardwick, 2014, Meyer et al. 2015). Macroinvertebrates are considered to be useful ecological indicators, because they are present in almost all freshwater systems, are easy to collect and identify and assemblages are known to change in response to human-induced stressors (Bailey et al., 2004). The concept of using macroinvertebrates indicators for ecological condition assessment, especially rivers has evolved rapidly since the 1970s, with national river bioassessment and monitoring programs used in Australia, Canada, North America and the UK and smaller programs applied in Spain, Portugal and Scandinavia (Bailey et al., 2014, Reynoldson et al., 2014).

The aim of this study was to determine the influence of differing types of protected area status and environmental attributes on the richness and composition of wetland macroinvertebrate assemblages. This was done by analysing data collected from 66 Tasmanian wetlands in best available condition. The results of our study will help guide the development of policy, planning and management to support wetland conservation both locally and further afield. Information from this study will provide a baseline dataset for future wetland monitoring undertaken to determine the effectiveness of conservation actions and the impacts of climate change.

We would expect wetlands located within the Tasmanian World Heritage Area (WHA) to be in near pristine condition and support the richest and most diverse macroinvertebrate assemblages because they are subject to the lowest levels of human influence and afforded the greatest management effort. Wetlands within National Parks and Public Reserves are also expected to be in good condition but may support less rich and diverse assemblages than those located within

Table 1
Definitions and descriptions of Protected Area Types (PAT) for Tasmanian wetlands sampled in the austral spring, 2012.

Protected area	Definition	Region	Description	Predicted macroinvertebrate richness and assemblage composition
World Heritage Area	Areas of land formally recognised through World Heritage listing. Most areas were listed in 1982. Managed under the Tasmanian Wilderness World Heritage Area Management Plan 2002 according to the International Union for Conservation of Nature (IUCN).	Central highlands	Wet sclerophyll state forest dominated by *Eucalyptus* sp. Restricted seasonal public access for recreational purposes, stock exclusion, marginal soils, cold climate.	High species richness, very diverse macroinvertebrate assemblages
National Park	National Parks and other Reserves are declared under the Nature Conservation Act 2002 that sets values and purposes of each reserve class. They are managed according to the National Parks and Reserves Management Act 2002 and the International Union for Conservation of Nature (IUCN).	Coast to central highlands	Wet sclerophyll state forest dominated by *Eucalyptus* sp. Limited public access for recreational purposes, stock exclusion, marginal soils, cold climate.	High-moderate species richness, high-moderately diverse assemblages
Public Land Reserve	Areas of governing districts reserved land created under the Crowns Land Act 1976 in an order signed by the Minister.	Lower watershed	Dominated by native vegetation. Limited public access for recreational purposes, stock exclusion, varied climate and soils, varied watershed land use, generally in agricultural or urban areas.	High-moderate species richness, moderately diverse assemblages
Directory of Important Wetlands in Australia	A database (established in 1993) that identifies nationally important wetlands, providing a knowledge base for land managers. The criteria for inclusion were agreed by ANZECC Wetlands 1994.	Coast and lower watershed	Dominated by native vegetation. May have limited access, stock exclusion, varied climate and soils, varied watershed land use, generally in agricultural or urban areas.	High-moderate species richness, moderately diverse assemblages
Private Land Covenant	Wetlands are protected through a perpetual conservation covenant, signed by the landowner and the State Government to manage the land for nature conservation. Covenants are legally binding under the Nature Conservation Act 2002 and registered on the land title.	Central and north eastern Tasmania	Regeneration of native vegetation. May have limited access, stock exclusion, varied climate and soils, varied watershed land use, generally in agricultural or urban areas.	Intermediate species richness, low-moderately diverse assemblages
Move this row to last i.e. least pristine Forestry Reserve	Areas managed under the Tasmanian Forest Practises code (Forest Practices Board1997/2000), a code of environmental practice enforced under the Tasmanian *Forest Practices Act* (1995). Mandatory riparian reserves and limited public access.	Lower watershed to central highlands	Native wet sclerophyll state forest dominated by *Eucalyptus* sp. Mandatory riparian reserves, stock exclusion, limited public access.	Low species richness, homogeneous assemblages
Tasmanian Land Conservancy property	Lands that have been purchased specifically to protect areas of high conservation value. This delivers long-term security for native species and ecosystems that are not adequately protected by other means.	Central highlands	Wet sclerophyll state forest dominated by *Eucalyptus* sp. Year round restricted access, stock exclusion, marginal soils, cold climate.	Intermediate species richness, low-moderately diverse assemblages.

the WHA because they are less remote and subject to a greater amount of human activity. The condition of wetlands listed with the DIWA and within Private Land Covenants, could vary considerably because the responsibility for wetland management belongs to a variety of different types of land-managers (both public and private), although guidelines are in place to assist with best conservation management practises. We find it difficult to predict the richness and diversity of wetlands on properties owned and managed by Tasmanian Land Conservancy (TLC) because although these properties now have strict management guidelines, many were acquired following forestry activities (logging). We would expect wetlands in Forestry Reserves to be moderately to highly disturbed when logging operations occur. These wetlands would be expected to recover well when there are long intervals (rotations) between logging episodes. The wetlands in this study were in Forest Reserves that had not been logged within last 20 years. Overall, we predicted that macroinvertebrate richness and diversity would be highest in wetlands located within areas with the highest levels of protection (World Heritage Areas and National Parks), lower richness and diversity in wetlands with less protection from human activities, and lowest in wetlands that are

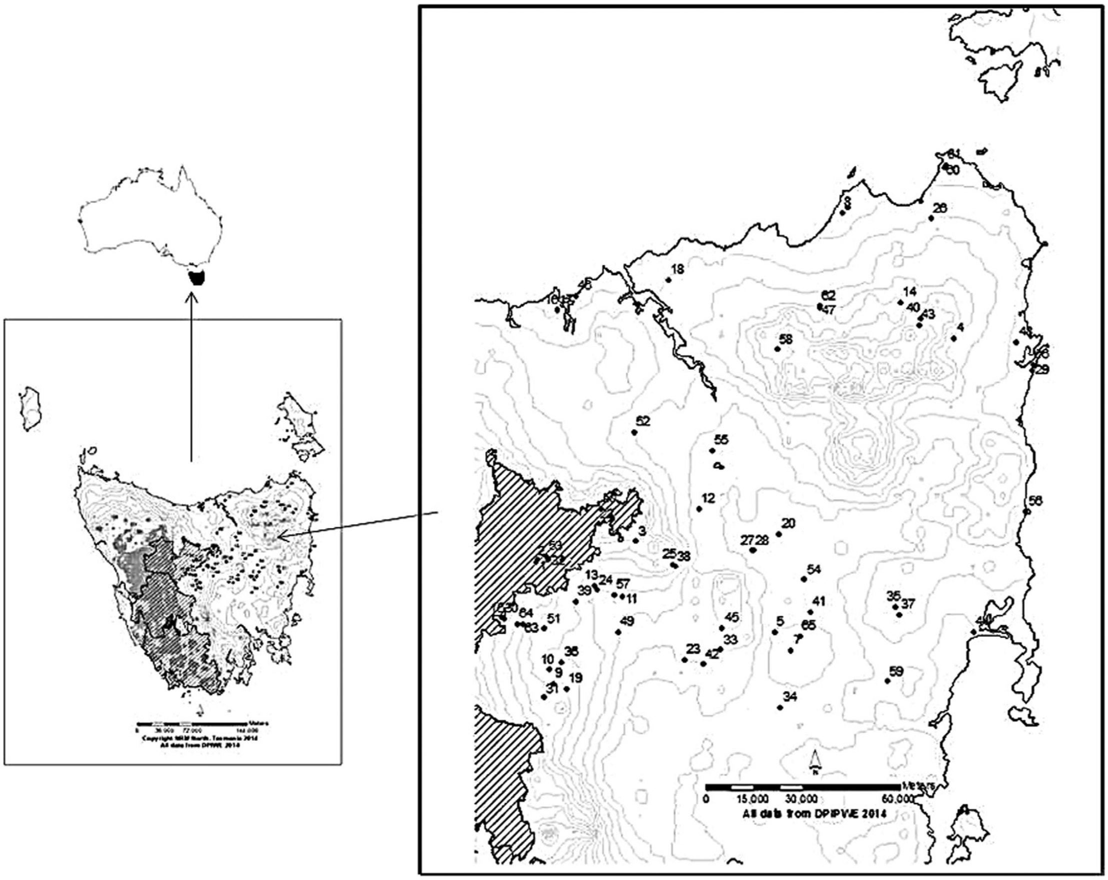

Fig. 1. Map of Tasmania showing the location of 66 wetlands sampled for macroinvertebrates and environmental attributes in the austral spring, 2012. Wetlands are labelled with a unique number which is linked to wetland attributes in Appendices A, B and C. Black diagonal lines denote World Heritage Areas (WHA). Rainfall isohyets (grey lines) are shown at 100 mm intervals below 2000 mm and at 20 mm intervals above 2000 mm. The location of Tasmania in relation to mainland Australia is shown on the upper map.

afforded no legal protection, are managed privately or are periodically disturbed (state forests). We also acknowledge that macroinvertebrate richness and diversity may be unrelated to levels of protection or disturbance but may vary according to changes in climate, topography or hydrological regime across the study region.

2. Materials and methods

2.1. Study area and selection of wetlands

Tasmania (Fig. 1) has a land area of 68 000 km^2 and a stable population of approximately 515 000 (7 people/km^2) (ABS 2014). Annual rainfall varies across the island from 600 mm in the north-east to 3000 mm in the south-west. A range of shallow, standing waters are present, including glacially formed wetlands in the highlands, and deflation basins, interconnected coastal wetlands of combined marine, glacial and aeolian origin and floodplain wetlands in the lowlands (Dunn 2005). These wetlands contain distinct wetland plant communities and a high proportion of endemic plant species (Kirkpatrick and Harwood, 1983). Many of the wetlands are in near-pristine condition, most likely because of the island's unique combination of climate, geology, geomorphology and low human population density (Dunn 2005).

The focus of this study was on wetlands in best available condition or reference condition, in protected areas. Sites in reference condition are considered to those minimally exposed to human stressors (Bailey et al., 2004). Best available condition is a term coined to capture the reality of selecting sites in reference condition, i.e. sites that are not affected by human-induced stressors (Bailey et al., 2014, Reynoldson et al., 2014) for bioassessment purposes and recognises that almost all accessible sites have been subject to some form of human-induced stress. We used three selection criteria to select wetlands in best available condition: (i) a form of protected area status existed that included and surrounded the wetland; (ii) the immediate watershed had no or minimal soil or vegetation disturbance; and (iii) there were undisturbed soils and vegetation in a proximal zone of 50 m from the wetland. An attribute-based typology and ground truthing were used to select wetlands meeting these criteria (unpublished Furlonge et al. 2015).

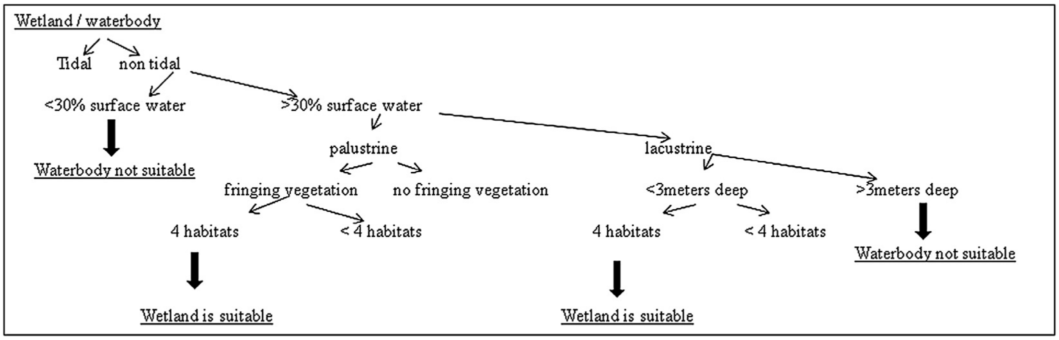

Fig. 2. Decision tree illustrating the hierarchical rule set developed for selecting freshwater wetlands for inclusion in this study.

A total of 66 protected wetlands in best available condition were selected, from approximately 20 000 polygons representing wetlands and waterbodies, in spatial datasets held by the state government (DPIPWE, 2008). Freshwater wetlands in best available condition, with optimum macroinvertebrate habitat were identified according to a hierarchical rule set (Fig. 2). The presence of multiple habitats based on vegetation zones defined by Cowardin et al. (1979) was considered to maximise the diversity of macroinvertebrates present (Table 2). A mapping and inventory process was undertaken to obtain a set of wetlands encompassing the variation in landforms and water regimes across the study area. Some wetlands selected in the central highlands are surface water resources regulated for the generation of hydroelectricity and are stocked with exotic fishes: brown trout (*Salmo trutta*) and rainbow trout (*Salmo gairdneri*), to support recreational fishing. These wetlands were included in this study because there was little evidence of major negative impacts and very few wetlands would have been available for study otherwise. Our study design did not enable us to investigate differences in the composition of macroinvertebrate assemblages between protected and non-protected wetlands. We subsequently added a family level dataset (available from a preceding study) that had been collected with identical methods for a small number of non-protected wetlands (six) that were also in best available condition. This additional dataset was included to support a preliminary assessment of the effect of protected area status versus no formal protection on wetland macroinvertebrate assemblages.

2.2. Protected area types and environmental attributes

Using Environmental Systems Research Institute ArcMap10 (GIS), watershed and wetland attributes were collated for protected and non-protected wetlands (Table 2) from existing spatial data from the Conservation of Freshwater Ecosystem Values database held by the Tasmanian government (DPIPWE, 2008), some of the attributes that were not available spatially were determined from a range of other sources (French, 1987; Environment_Australia, 2001). For attributes not available from these sources (Water Regime (WR), Dominant Habitat (DH) and Proximal Zones (PZ); Table 3), data were collected at the same time as the macroinvertebrates were sampled and water quality parameters were measured. Using GIS, seven categories of Protected Area Type (PAT) were derived primarily from land tenure data and staff from Tasmanian Government agencies, and assigned for each wetland (Table 1). We did not have the resources to quantitatively sample wetland fish assemblages in our wetland study, however, we were able to determine the presence of introduced fish (*Salmo sp.*) from a range of sources. These included visual observations made whilst sampling macroinvertebrates, advice provided to trout fisherman (French, 1987), information provided on websites (www.bonzle.com accessed 2015; www.environment.gov.au accessed 2015; www.parks.tas.ogv.au accessed 2015) and local knowledge provided by members of fishing clubs.

2.3. Collection of macroinvertebrate samples and water quality data

All protected wetlands (66) were sampled in the austral spring of 2012 and the six non-protected wetlands in the austral spring of 2011. Two macroinvertebrate samples were collected from each study wetland using a rapid assessment method, described as follows. Samples were collected by sweeping a long-handled, D-shaped, 250-μm mesh net, in a zig-zag motion from the substrate and through the water column to the water surface for two minutes per habitat. The substrate was not actively disturbed beyond moving the D net among macrophytes. Four habitats were sampled: (i) fringing vegetation samples were taken from the waters-edge and approximately one metre into the waterbody, containing trees or shrubs at the high water mark or macrophytes and grasses at the low water mark; (ii) emergent macrophyte samples were taken from deeper water, moving away from the fringing zone and among the emergent macrophytes, containing a mixture of plants; (iii) submerged macrophyte samples were taken from deeper water moving away from the emergent zone, containing mixed plants to a depth where light ceased to penetrate sufficiently to sustain plant growth (in shallow wetlands, this was to a depth were the plants life cycle was entirely underwater); and (iv) open water column samples were taken from deeper water lacking submerged macrophytes to a depth of 1.5 m (in shallow wetlands this was above submerged macrophytes). Samples from the fringing and emergent habitats were combined to form sample 1 and the submerged macrophyte and the

Table 2
Wetland attributes recorded and watershed attributes collated for each wetland. The categories for Protected Area Type, Proximal Zone, Water Regime and Dominant Habitat variables are defined in Tables 1 and 3. The GIS database is held by the Conservation of Freshwater Ecosystems Values program within the Tasmanian State Government (DPIPWE, 2008).

Attribute scale	Attribute	Attribute measure	Instrument/analytical method/data source
Wetland	Water temperature	°C	Thermometer
Wetland	pH	pH	WTW 3110 m
Wetland	Conductivity	μS/cm	WTW 3210 m
Wetland	Turbidity	NTU	HACH 2100Q
Wetland	Total nitrogen	mg/L	APHA Standard Method, University of Canberra
Wetland	Total phosphorus	mg/L	APHA Standard Method, University of Canberra
Wetland	Substrate composition	Categorical	Field assessment
Wetland	Surrounding vegetation	Categorical	Field assessment
Wetland	Proximal zone	Categorical:	Field assessment
Wetland	Protected area type	Categorical	Field assessment
Wetland	Water regime	Hydoperiod	Field assessment
Wetland	Dominant habitat	Macrophyte-dominated or Sediment-dominated	Field assessment
Watershed	Surrounding sub-watershed landuse	Categorical	Field assessment
Watershed	Soils	Acid Sulphate Soil type	GIS
Watershed	Site Coordinates	latitude and longitude	GIS
Watershed	Rainfall zone	mm per annum	GIS
Watershed	Landform	type	GIS
Watershed	Land tenure	Protected area type	GIS
Watershed	Vegetation	group	GIS
Watershed	Watershed land-use	type	GIS

Table 3
Description of Water Regime, Dominant Habitat and Proximal Zone categories defined for wetlands sampled in the austral spring 2012 in central and north eastern Tasmania.

Category	Description of category
Water Regime	
Permanent	Water is always present.
Seasonal	Contains water on a predictable seasonal cycle and dries during summer or autumn each year.
Dominant Habitat	
Macrophytes	Habitat is dominated by emergent or submerged plants.
Sediments	Habitat is sediment (not plant) dominated, substrate sediments include: silt, sand, gravel, pebble, cobble or boulder.
Proximal Zone	
Undisturbed	No obvious signs of human activities in proximal area (50 m).
Disturbed	None of the following activities present within 50 m of the wetland: visible signs of recreational activity; vegetation clearing; earthworks; cropping; grazing or contains Cyprinidae sp.(carp).
Rehabilitated	Proximal protection provided by fencing or planting of vegetation and no obvious human activities.

open water habitat samples were combined to form sample 2 (Table 2). Samples were gently agitated and the entire sample was rinsed from the D net into shallow white trays for live picking for a total of 30 min. Collection was initially limited to 20 individuals of plentiful taxa to ensure all types of taxa were picked and to avoid bias towards picking larger, more mobile taxa. The relative abundance of any unpicked taxa was estimated and recorded into four categories: 0–20, 21–50, 51–100 and >100 individuals. All samples were sorted on site and preserved in 80% ethanol. All sampling was undertaken by the same individuals (lead author and assistant) to maintain consistency across all sites. Electrical conductivity, pH and turbidity were measured at each macroinvertebrate sampling site, using hand-held metres (Table 2). Water samples were collected for the analysis of total nitrogen and total phosphorus concentrations using standard methods at the Institute for Applied Ecology, University of Canberra, Australia.

Macroinvertebrates were subsequently identified to the lowest taxonomic level with the aid of a stereo-microscope and macroinvertebrate keys. Oligochaeta were identified to order only. Hydracarina, Ancylidae, Lymnaeidae, Glacorbidae, Phreatoicidae, Elmidae, Scirtidae and Turbellaria were identified to family or sub-family. All other specimens were identified to genus, species or morpho-species, using relevant keys (Hynes 1989, Harvey an Growns 1998, Jackson 1998, Dean 1999a, b, St Clair 2000 a, c, b, Hawking 2001, Tsyrlin 2001, Lansbury and Lake 2002, Theischinger 2002, Watts 2002, Gooderham and Tsyrlin 2003, Dean and St Clair et al. 2004, Madden 2010, EPA 2012) and assistance from taxonomic experts.

2.4. Data analysis

We used ANOVA's and Tukey multiple comparisons of means (95% confidence level) using pairwise differences, to compare macroinvertebrate richness (at taxonomic levels of species and family) between categories of protected area types, between dominant habitats, between proximal zones and between water regimes as described in Table 3 (Quinn and Keough, 2002). A Bartlett test was used to ensure assumptions of homogeneity of variances were met prior to each

ANOVA. All univariate statistical analyses were performed with R (R_Development_ Core_Team 2014). Multivariate analysis was undertaken using routines in the Primer + Permanova (V6.1.13/PRIMER-E Ltd., Plymouth, UK) software package to explore patterns in the macroinvertebrate assemblage data and to identify relationships between assemblages and the 19 environmental attributes listed in Table 2. The two macroinvertebrate samples taken from each wetland were combined to produce a single resemblance matrix (Bray–Curtis dissimilarity) based on presence–absence data and using individual wetlands as replicates. We compiled summary statistics on the numbers of taxa and individuals per site. We did exploratory analysis on the macroinvertebrate dataset to quantify any variation in composition, to identify the nature of this variation and to determine any overlap between species that occur in species-rich and species-poor wetlands. Measures of the nestedness of species (based on presence–absence data) were calculated using the nestedness program ANINHADO (Guimaraes and Guimaraes, 2006). The NDOF metric (Almeida-Neto et al., 2008) calculates nestedness independently among rows and among columns which allows the calculation of nestedness among sites or taxa.

The environmental attributes listed in Table 2 were added as factors to the macroinvertebrate resemblance matrix in Primer + Permanova and individually tested in all multivariate routines. Multi-dimensional Scaling (MDS, Bray–Curtis similarity, 25 restarts, Kruskal fit 1, minimum stress 0.01 and configuration plot selected) was used to visually contrast wetlands based on macroinvertebrate assemblages at family and species levels for each factor. This is a straight forward way of comparing sites, as those grouped are similar and those far apart are different (Clarke and Warwick, 2006). To test for assemblage differences between groups of wetlands and each factor, Analysis of Similarities (ANOSIM, one way, single factor, 999 permutations) was used. We then used the SIMPER routine (Bray–Curtis, single layout) to identify the main taxa contributing to the compositional differences between groups of wetlands for each factor. Prior to testing for significant relationships between groups of environmental attributes (Table 2) and macroinvertebrate assemblages, the attributes were added to Primer + Permanova as a data matrix with a square root transformation, followed by normalisation to place all attributes on similar scales in a resemblance matrix with a Euclidean distance measure. Permanova, is a routine for testing simultaneous responses of variables to factors (Anderson et al., 2008) and we used Permanova to identify any significant variation between categories of Protected Area Types, Proximal Zones, Dominant Habitats and Water Regimes. We used the routine BEST (BioEnv, resemblance matrix, 99 permutations, rank correlation = Spearman, maximum number of best results = 10) to determine the most influential environmental attributes and the percentage each attribute contributed to the composition of the assemblage. Distance based Redundancy Analysis (dbRDA, number of RDA axes = 10) was used to determine the greatest discrimination among groups of wetlands and to assess the statistical significance of the relationships between macroinvertebrate richness and relative abundance data resemblance matrices and environmental attributes.

3. Results

The 66 protected Tasmanian wetlands (Appendix A) sampled in spring 2012 included representatives from seven different types of protected areas and the landforms present across the study region (floodplains, undulating plains, low, mid and high slopes; Table 4). Three wetlands were listed as Ramsar sites (these were included within Protected Area Types). Rainfall ranged from 451 to 1668 mm per year and elevation ranged from sea level to 1161 m above sea level. The majority of wetlands (56) sampled had a permanent water regime while ten displayed a seasonal drying pattern. More wetlands were macrophyte-dominated (45) than sediment-dominated (21) (Table 4), only small patches of mixed macrophyte species were present in the latter. The proximal zone was undisturbed at 32 wetlands, while 14 wetlands displayed some evidence of disturbance from human activities, mainly from vehicle access. Rehabilitation of the proximal zone in the form of fencing to allow natural regeneration had occurred at one third of the wetlands (Table 4). The six non-protected wetlands sampled in spring 2011 were located on floodplains, undulating plains and low slopes within lower areas of the study watersheds. All had a permanent water regime, macrophyte-dominated habitats and an undisturbed proximal zone.

Two hundred and eighteen macroinvertebrate species (or morpho-species) belonging to 95 families were recorded from the 66 protected wetlands (Appendix C). These included eight families of Mollusca, seven Crustacea and 79 Insecta. An average of 33 species were collected per site, with a range of 9–55 taxa. An average relative abundance of 496 individuals per wetland was recorded and richness increased with abundance. Wetlands with a permanent water regime contained from 9 to 55 species and wetlands with a temporary water regime contained from 18 to 55 species. Sixty one percent of the species occurred at four or less sites and so were considered rare (Norris et al., 1982; Marchant, 2002) (Table 5). Seventy one species occurred only once. Twenty one species occurred at 30% of the sites and could be considered the 'core' macroinvertebrates for the 66 wetlands (Batzer and Ruhi, 2013). Overall our dataset (species presence–absence) was not significantly nested ($P = 0.98$ Er model; $P = 1.00$ Ce model) ($P > 0.05$).

The most commonly recorded families were Leptoceridae, Ceinidae, Hydrachnidae and Corixidae. These families, in combination, accounted for 21% of the total abundance. Chironominae and Dytiscidae were the most widespread taxa occurring at 91% and 88% respectively of wetlands. There was little evidence of dominance by any particular family across the wetlands, with 25 families accounting for 90% of the total families present. Over the 66 protected wetlands we recorded eight families of Mollusca, seven Crustacea and 79 Insecta. Of the Insecta families, four were Coleoptera and eight were Hemiptera (Appendix C). Thirty five wetlands contained at least one family of Mollusca, 53 at least one family of Crustacea and 60 contained Insecta. A number of species in the families Leptophlebiidae and Phreatoicidae and order Trichoptera appeared to be new, having not been described or confirmed from elsewhere in Australia. Some species of Ostracoda and Gyrinidae had been recorded from the Australian mainland but represented new records for Tasmania.

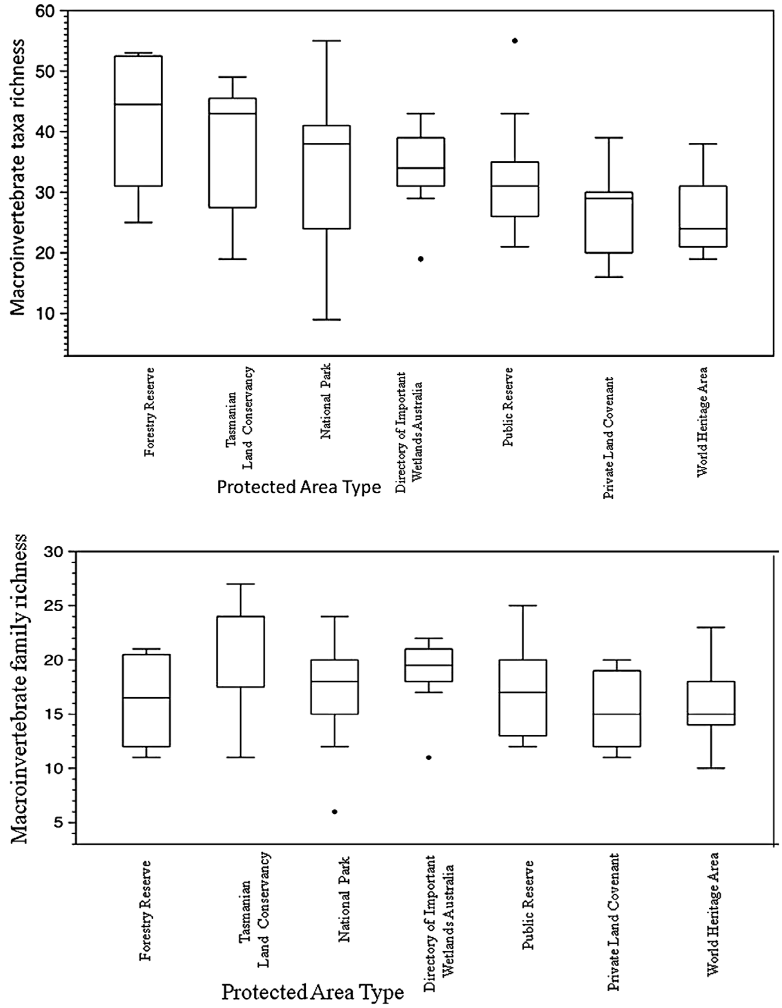

Fig. 3. (a) Differences in the number of macroinvertebrate taxa recorded from the 66 Tasmanian wetlands sampled in the austral spring, 2012 with different types of protected area status (*x*-axis); and (b) Differences in the number of families of macroinvertebrates recorded at wetlands with different types of protected area status (*x*-axis). The horizontal lines inside the boxes represent the medians, the top and bottom edges of the boxes represent 25%–75% quantiles, and whiskers represent the range of the data.

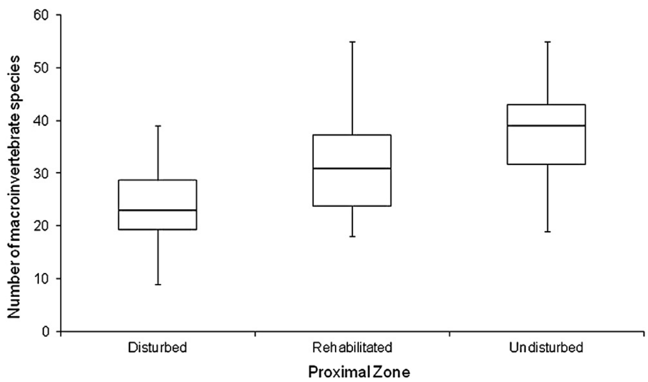

Fig. 4. Differences in the number of macroinvertebrate taxa recorded from the 66 Tasmanian wetlands sampled in the austral spring, 2012, with differing proximal zones (*x*-axis). The horizontal lines inside the boxes represent the medians, the top and bottom edges of the boxes represent 25%–75% quantiles, and whiskers represent the range of the data.

Table 4
Number of study wetlands in categories of Protected Areas, Water Regime, Dominant Habitats and Proximal Zones.

Category	Number of wetlands in study
Protected Area	
National Park	19
Tasmanian Land Conservancy	7
Directory of Important Wetlands in Australia	10
Private Land Covenant	10
Public Reserve	12
World Heritage Area	5
Forestry Reserve	4
Water Regime	
Permanent	57
Seasonal	9
Dominant habitat	
Macrophytes	45
Sediments	21
Proximal Zone	
Undisturbed	32
Disturbed	14
Rehabilitated	20

Table 5
Macroinvertebrate taxa occurring in >50% of wetlands, listed in order of dominance.

Taxon	Percentage of wetlands that taxa occur in
Chironominae	90.9
Dytiscidae	87.9
Leptoceridae	86.4
Tanypodinae	84.8
Ceinidae	80.3
Corixidae	78.8
Orthocladiinae	66.7
Hydrachnidae	63.6
Oligochaeta	56.1
Planorbidae	53.0
Coenagrionidae	51.5
Hydrophilidae	51.5
Lestidae	51.5

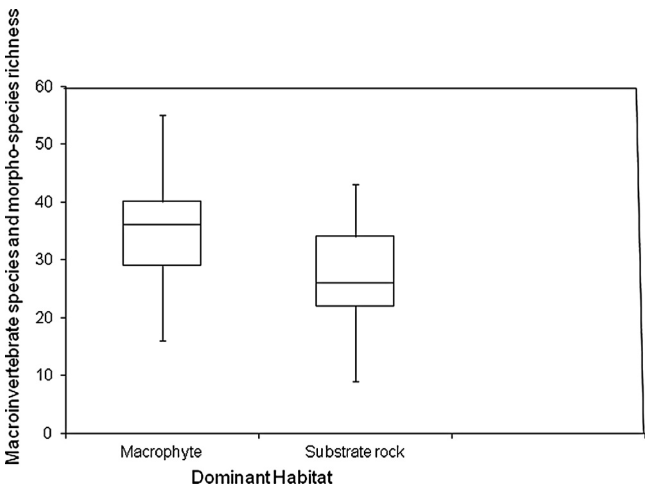

Fig. 5. Differences in the number of species of macroinvertebrates recorded from the 66 Tasmanian wetlands sampled in the austral spring, 2012 dominated by macrophytes or sediments. The latter includes combinations of clay, silt, sand, gravel, pebble, cobble or boulder. The horizontal lines inside the boxes represent the medians, the top and bottom edges of the boxes represent 25%–75% quantiles, and whiskers represent the range of the data.

The highest number of species were collected from Forest Reserves (mean = 42, SE ± 13.3) (Fig. 3(a)) and the highest number of families from Tasmanian Land Conservancy reserves (mean = 21, SE ± 4.8). In contrast, the lowest number of

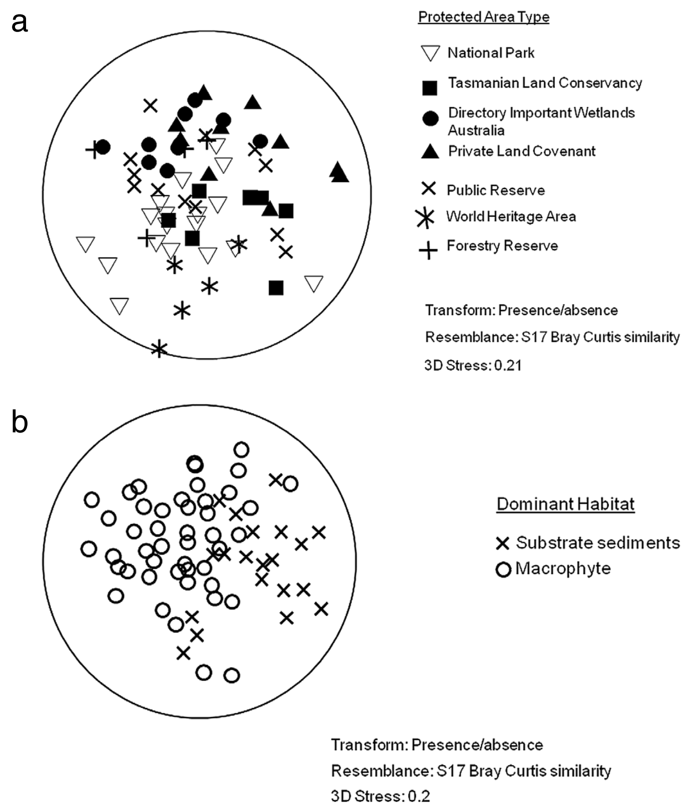

Fig. 6. Multi-dimensional Scaling (MDS) ordination of macroinvertebrate assemblages (presence–absence transformation) from 66 Tasmanian wetlands sampled in the austral spring, 2012. Wetlands are coded by symbols for: (a) Protected Area Types: open triangles = National Park; closed squares = Tasmanian Land Conservancy, closed circles = Directory Important Wetlands Australia (includes Ramsar); closed triangles = Private Land Covenant, X = Public Reserve; star = World Heritage Area and + = Forestry Reserve; and (b) Dominant Habitat: X = sediments-dominated; and open circle = macrophyte-dominated.

species were recorded from wetlands in World Heritage Areas (mean = 26.6, SE ± 7) (Fig. 3(a)) and Private Land Covenants (mean = 27, SE ± 5.2) (Fig. 3(a), (b)). However, Tukey tests revealed no significant differences in species or family richness among Protected Area Types or Water Regimes ($P < 0.05$). Species occurring at a single site were most prevalent at wetlands in Tasmanian Land Conservancy properties where 21 species were recorded, Public Reserves contained 14, all other Protected Area Types had either five or eight single occurrences of a species. Macroinvertebrate species richness was significantly higher ($P < 0.05$) in wetlands with an undisturbed Proximal Zone (mean = 38, SE ± 1.6) compared to those with disturbance present (mean = 24, SE ± 1.9). The species richness at wetlands where rehabilitation had occurred within the Proximal Zone was intermediate between these two (Fig. 4). Wetland habitat significantly influenced species richness, with macrophyte-dominated habitats richer than sediment-dominated habitats ($P < 0.05$; Fig. 5). Fewer families (46 less) were recorded in the non-protected wetlands than protected wetlands, however, the low sample size of the former (six wetlands) means that we cannot attribute any statistical significance to this result. Macroinvertebrate family richness was not significantly different between wetlands with and without exotic fishes (*Salmo sp.*) or between protected and non-protected wetlands ($P > 0.05$).

Ordination based on species presence–absence data showed no distinct grouping of wetlands suggesting there was no 'Core' group of macroinvertebrates. There were no major differences in macroinvertebrate assemblages associated with Protected Area Types (Fig. 6(a)), Proximal Zones or Water Regimes. However, a separation was visible between the two types of Dominant Habitats (Fig. 6(b)). The MDS ordination plot (Fig. 7) indicated that the six non-protected wetlands tended to group separately to those of the protected wetlands but ANOSIM (Global $R = 0.117$, $P \geq 0.1$) indicated that the difference between the two groups was not significant ($P > 0.05$). Thirteen taxa that occurred in more than 50% of wetlands were identified (using SIMPER) as contributing to the compositional differences between wetlands (Table 5). The response of wetland assemblages varied with the different categories of Dominant Habitat and the different categories of Water Regime (Permanova: *Pseudo-F* 4.2, $P < 0.001$, ANOSOM: Global $R = 0.254$, $P < 0.001$; *Pseudo-F* 2.6, $P < 0.003$ Global $R = 0.306$, $P < 0.001$ respectively), Proximal Zone (*Pseudo-F* 2.0, $P < 0.001$ Global $R = 0.159$, $P < 0.001$) and to a lesser extent Protected Area Types (*Pseudo-F* 1.1, $P < 0.3$). Types of wetlands described by landform (Appendix A) were not significantly different and richness did not change significantly with latitude, longitude or elevation ($P > 0.05$). The assemblage patterns were weakly related to these factors and the correlation between factors was low ($Rho = 0.20$, $P < 0.1$). No single water

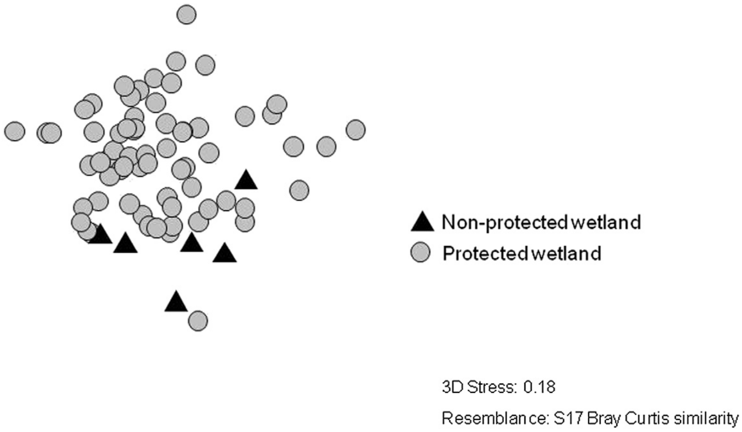

Fig. 7. Three dimensional ordination (MDS) of 66 protected wetlands and 6 non-protected wetlands showing macroinvertebrate taxa at family level.

quality attribute had a strong relationship with the among sample patterns of the macroinvertebrate assemblages, although in combination a small match was evident (BEST (Bio-Env); $P < 0.26$). dbRDA showed fitted variation of the water quality attributes, 31% on the X axis and 25% on the Y axis. At a watershed level, again there was no strong relationship with any single attribute, although the combination of landform, rainfall, latitude, elevation and longitude provided the strongest match (BEST (Bio-Env); $P < 0.2$). dbRDA showed fitted variation to these attributes, 28% on the X axis and 18% on the Y axis. Relationships between macroinvertebrate assemblages (macroinvertebrate richness and relative abundance resemblance matrices) were most influenced by the combination of Dominant Habitats, Protected Area Types, Proximal Zones and Water Regimes (Fig. 6) with dbRDA showing a fitted variation of 41% on the X axis and 31% on the Y axis. No significant difference (ANOSIM Global $R = 0.118$, $P = 0.2$) was observed in the composition of macroinvertebrate assemblages in wetlands that contained exotic fishes (*Salmo sp.*) and those that did not.

4. Discussion

We used data on aquatic macroinvertebrates collected at the habitat, wetland and regional scales to examine the influence of protected area type (Table 1) and other environmental attributes (Table 2) on wetland biodiversity (Table 5). The number of wetlands included in our study was relatively high (66) and they spanned a variety of landforms. None of the watershed attributes or physico-chemical wetland attributes (Table 2) measured, were strongly associated with groups of wetlands. However, we did find small relationships with combined water quality attributes, watershed attributes and assemblage composition. Our prediction that we would detect higher species richness and differences in assemblage composition between the most highly protected (global treaties and national parks) and least protected (local reserves and private ownership) was not supported. The lack of statistically significant differences between macroinvertebrate richness at both the species and family level, across all types of protected areas (Fig. 3(a); (b)) and the lack of a discernible pattern in the composition of macroinvertebrate assemblages between categories of protection (Fig. 6(a)) suggested that all types of protection had a similar influence on aquatic invertebrates. Although many different types of protected areas exist, there is little information on how the type of protection influences conservation outcomes. The relatively high number of taxa (species and morpho-species) recorded at the 66 study wetlands suggest that all types of protected areas in Tasmania support the conservation of wetland macroinvertebrates.

We did not have sufficient data to rigorously test the effect of protected versus non-protected area status on macroinvertebrate diversity, partially because a large proportion of the Tasmanian landscape is in some form of protection. The inclusion of six non-protected wetlands revealed no significant difference between the composition of macroinvertebrate assemblages or richness in wetlands with or without a formal protected area status (Fig. 7). However, this result needs to be confirmed in a future study that includes a larger number of non-protected wetlands. Our result may also have been influenced by the fact that the six non-protected wetlands were also considered to be in best available condition.

The majority of protected area categories included in our study were chosen and managed to support terrestrial conservation objectives, rather than wetland values. However, our results suggest that the latter were also afforded protection. Accordingly, our results suggest that areas reserved primarily to protect terrestrial biodiversity, may also be of value in protecting wetland biodiversity. This is an important finding because few protected areas are created specifically for the protection of fresh waters (Saunders et al., 2002; Hermoso and Kennard, 2012).

When wetlands are highly nested, conservation priorities can be directed to protect species-rich wetlands because protecting these will maximise biodiversity outcomes. However, we found that the study wetland assemblages were idiosyncratic, rather than nested, with a low dominance of individual families. We were not able to predict composition based on richness, indicating that management actions could not be targeted to protect specific wetlands. Mollusca were considered to have the greatest potential to act as a surrogate indicator of macroinvertebrate richness in a global study, that included both permanent and temporary wetlands (Ruhí et al. 2014). Simple congruence analysis of our dataset suggests this was not the case for Tasmanian wetlands, because Mollusca were recorded in only 53% of wetlands. Our results tend to support the findings of (Westgate et al., 2014), who suggested that a range of taxa should be considered for conservation planning where the goal is to prioritise locations, or actions for biodiversity conservation.

The number of macroinvertebrate species and morphospecies (218) recorded in our study appears to be high in comparison to the results of other studies. For example, we recorded 95 families from 66 wetlands in comparison to a global study by Batzer and Ruhl (2013) which listed 175 families across 477 wetlands. Direct comparisons with individual wetland studies are difficult, because of differing taxonomic resolution, differences in sampling methods and differing spatial and temporal sampling intensities. Our finding of 218 species or morpho-species from a comparably low number of wetlands (66) suggests that it is likely that Tasmanian wetlands are species rich on a global scale.

The state of the proximal zone (the terrestrial zone within 50 m of the wetland edge) and the type of aquatic habitat present (macrophyte or sediment-dominated substrates; Table 3), were the most important determinants of macroinvertebrate richness and assemblage composition across all types of protected wetlands in our study. A study of rivers in south-eastern Queensland found that variables acting proximal to stream survey sites were more suitable for predicting macroinvertebrate assemblage composition than variables acting at the watershed scale (Peterson et al., 2011). Our results support this finding; wetlands with undisturbed proximal zones had richer macroinvertebrate communities than those with disturbed proximal zones (Fig. 4). Other studies have identified watershed land use as an important determinant of freshwater biodiversity patterns (Stendera et al., 2012). Our results did not show this, possibly because we had chosen wetlands in best available condition rather than wetlands located along a land use gradient. Human disturbance is known to have a major impact on wetland invertebrate diversity (Batzer, 2013) and our results supported this finding with respect to human influences on the proximal zone. The wetlands with the highest amount of human disturbance in the proximal zone were the least species-rich. Fencing of the proximal zone, which acted to reduce stock and vehicle access, represented a form of rehabilitation that appeared to be effective. The species richness recorded at wetlands where this had occurred was intermediate between those of wetlands with disturbed and undisturbed proximal zones.

Many studies have shown that the composition of wetland macroinvertebrate assemblages is influenced by water regime (Neckles et al. 1990, Wellborn et al., 1996, Robson and Clay, 2005, Vanschoenwinkel et al., 2010, Sim and Davis et al. 2013, Chessman and Hardwick, 2014). However, specific relationships between invertebrate community structure and hydrology are considered to be difficult to interpret (Batzer, 2013). No significant differences were detected between macroinvertebrate richness in permanent and seasonal wetlands in this study.

The wetlands in Forest Reserves contained large amounts of terrestrial plant material (mainly leaves and bark *of Eucalyptus* spp.) as benthic detritus. Terrestrially-derived organic material is known to increase in streams and rivers following forest harvesting (Stone and Wallace, 1998; Smith et al., 2009). Fuchs et al. (2003) found that macroinvertebrate abundance and biomass tend to increase as a result of forest harvesting. Silsbee and Larson (1983) related macroinvertebrate abundance in logged streams to increased stream organic matter derived from terrestrial plant material. Leptoceridae (caddis flies) use detritus as case-building materials and the ready availability of detritus in Forest Reserve wetlands may explain the high number of caddis species recorded from these wetlands. The wetlands we sampled in Forest Reserves had not been logged for at least 20 years and our results indicate that over this period of time, assemblages had become diverse with a high richness.

In an earlier study, Kirkpatrick and Tyler (1988) noted that the nature conservation values of many Tasmanian wetlands had been compromised, even when wetlands were located within National Parks. The main focus of their study was wetland plant communities and they noted that many fringing marshes had been lost when wetlands were drowned within hydroelectric impoundments. Recreational fishing in Tasmanian National Parks and World Heritage Areas is encouraged, through the stocking of wetlands, deep lakes and rivers with predominantly *Salmo spp*. (brown and rainbow trout). The composition of the invertebrate assemblages of standing waters is known to be altered by fish predation (Wellborn et al., 1996) and *Salmo spp*. are considered to be detrimental to native aquatic fauna (Kirkpatrick and Tyler, 1988). Our study did not detect a significant difference in the composition of macroinvertebrate assemblages or macroinvertebrate richness in wetlands with or without *Salmo spp*. We were not able to comprehensively compare wetlands with and without fish (regardless of native or introduced status). A further study that accurately assessed wetland fish populations and their effect on macroinvertebrates would be useful.

Studies of riverine macroinvertebrate assemblages suggest that high species richness and diverse community composition are indicative of good ecological condition (Norris and Thoms, 1999). Accordingly, the richness and diversity of macroinvertebrate assemblages recorded in Tasmanian wetlands, across different rainfall zones, topography and protected area types, suggest that these wetlands are in very good ecological condition. Our results will be useful for future analyses of wetland biodiversity across gradients of human disturbance, particularly urbanisation, as we have described biodiversity patterns in a region of the world that has a relatively low human population density. The results of this study contribute to the understanding of the macroinvertebrate component of wetland biodiversity, within a temperate region of the world and more broadly to global wetland biodiversity. Our data come from an understudied region (Tasmania, Australia) and provides macroinvertebrate species and family lists from wetlands in good condition. This information provides baseline dataset which can be used in future wetland bioassessment and monitoring programs. Our results indicate that for Tasmanian wetlands within protected areas, it is local factors that most influence macroinvertebrate richness and composition. Namely the presence of aquatic plants within the wetland, and the lack of human impacts in the terrestrial zone immediately adjacent to the wetland. These results suggest that for these wetlands, the macroinvertebrate fauna will be best conserved by minimal disturbance of proximal lands.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.gecco.2015.07.007.

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